Cone penetration testing, CPTu

Preface

Our company is Environmental Mechanics AB or short Envi. A Swedish company developing, producing and marketing systems for cone penetration testing (also known as CPT or CPTu) which is used for soft soil investigations plus equipment for drill data recoding (an acronym is MWD). This document is intended as an introduction to cone penetration testing. A CPTu probe is used to penetrate the ground to a level where it is no longer possible to go any deeper or when the test depth is considered sufficient. This procedure is often referred to as a push and is executed at a constant speed of 2 cm/sec during which data from several sensors in the probe are registered. You can be piggyback several additional/optional sensors to the CPT probe. As of today we can provide both seismic module and a resistivity module for add on to our CPT probe. Our CPTu probe is called Memocone™ and is available for several operational modes. All development and production of all our systems is done in Sweden.

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History

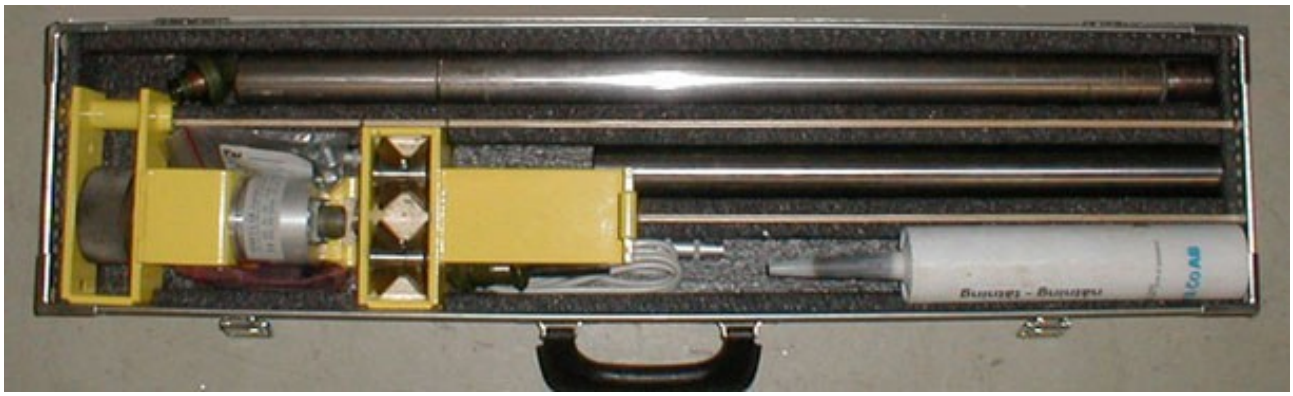
Ground investigations using cone penetration was first done in the Netherlands in the early 1930th. They used a mechanical penetrometer. Electrical cones were first developed around early 1960th but came into more common use in the 1980th when the piezometer had been developed. The first cones could only read tip force and later sleeve friction. The new piezometer probe could read also pore water pressure giving you the possibility to determine ground water level. This probe type is also known as a CPTu.

Envi was started around 1985 and delivered the first drill data logger a year later and the first CPTu probe not much later. The cone is known as Memocone. The name indicates it's built in electronic memory making wireless operation possible. Since then Envi has developed a seismic add-on enabling SCPTu investigations and a resistivity add-on enabling resistivity/conductivity measurement to be executed at the same push as CPT investigation is done. This document will focus on the basic CPTu functionality and leave the add-ons for later descriptions.

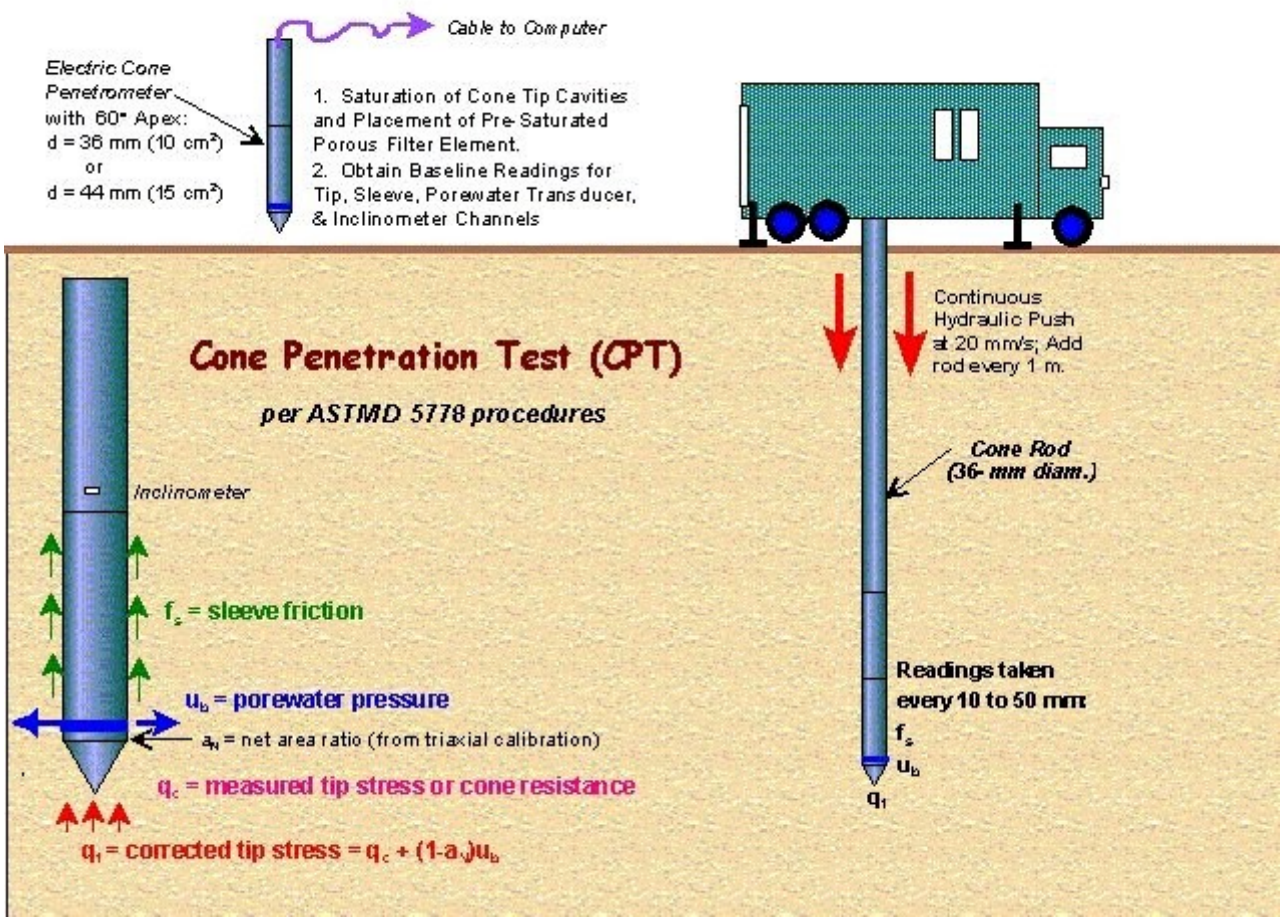
Since the company was started Envi has developed and sold several generations of CPTu probes and data loggers. The current model is called Envi Logger C1 and CS1. These loggers were introduced to market in mid 2010. They are PC based and fully digital and uses a CANopen data bus for data transfer to and from sensors. Below is an image of the two logger types. More details about them later in this document.

The Memocone without battery tube

Complete probe set including Memocone, battery tube, the yellow wheel on the rod depth meter + accessories.



The image below shows a complete system including pushing machine, in this case a truck, and the parameters that are measured.



Our two different types of data loggers. The logger for registering both CPT and SPT is below and slightly larger.

What is measured?

When running CPT tests you send down a probe into the ground. This is also known as in-situ testing. Data from the CPT probe can be sent to surface during the penetration by means of a cable/ cord or by using an acoustic system. You can also rely on your rig sensors only and use only the built in memory in our Memocone or equivalent CPT probe. The draw back of using memory mode is that you can not know if you begin to come close to maximum load or if the probe starts going at an angle. Regardless of what type of equipment you use what really matters is:

1. Your measurement is correct and complete
2. You know how to translate your sensor data to real world aspects (i.e. how to translate probe data into soil types)

Parameters normally measured are:

- Time
- Drill hole length, often referred to as Depth but drilling may be executed horizontally or even vertically in the opposite direction. When you combine Time and Depth you can get rate of penetration or short ROP which describes how fast you are drilling. Depth resolution varies between different systems but Envi Logger C1 has default resolution 1 cm/10 mm when plotting depth
- Tip force also known as Qc. This is measured in MPa which is a bit odd for force but this is quite clever since it makes tip area unimportant and thus enabling use of different size probes with the same result for the same soil type.
- Sleeve friction, also known as Fs. This is meassured in kPa for the same reason as Qc is measured in Mpa
- Pore pressure. There are actually three different pore pressures that can be measured according to current standards. A huge majority of CPT tests is equipped with only the second pore pressure meter, also known as U_2. Using other sensors, which are U_1 and U_3, is unusual.
- Inclination. This parameter is for registering how much the probe is inclining (at an angle as compared to vertical)
- Temperature. This can be important since electronics and sensors can be be affected by temperature changes. The Memocone is equipped with built in compensation for temperature changes so you need to consider this very little with our system. The registration in the Memocone is influenced only if temperature changes very swiftly since there is some small delay in compensation.

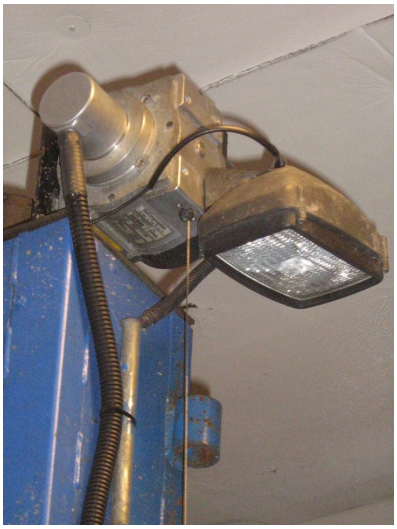
Commonly used add-ons to the CPT are:

- Resistivity add-on for registering ground resistivity/conductivity. This can be used for determining moisture and salt content in ground
- Seismic add-on can be used as a complement for cross referencing and validating soil type determination from CPT parameters

How are parameters measured?

Most parameters when running CPT tests are registered in the probe itself but depth is measured separately. I will not describe time since that is not an actual parameter but more like an index.

Depth is measured using a multiturn encoder with 12 bits single turn resolution and 18 bits multiturn resolution and CANopen interface. The transducer is normally IP67 but also IP69k is available. The sensor is typically mounted on a wire house module as per image to the left below or using a mounting bracket on the drill unit and supplying the axle with a cogwheel + a chain will be mounted all along the mast as per image in the middle below. Another common depth meter is the wheel on the rod solution as depicted to the right below. This can be mounted and demounted easily and can "travel with the system" if you want to use one registration system on several drill rigs or equivalent.



Feed force can be measured in several ways:
1. You use a strain gauge to get data. This is typically done using an S-shaped transducer
2. You read hydraulic pressures on both sides of the hydraulic piston and consider piston area on both pulldown and holdback side of the piston to get feed force.
Either way above you still need to calibrate the sensor output to an actual force which can be done using several segments to compensate for possible non linearities. This is done by using a very accurate scale and and reading pressure or strain gauge output for many forces. This is only logged to have machine force logged in the file for informative use. It is not used for determining soil type.

Qc, Fs, U2 + some more (as per earlier chapter) are all measured by the probe.

The probe is pushed into the ground at a speed of 2 cm/second until you reach a predefined depth or you can not go further due to obstacles or you are satisfied with the resistance you get or whatever are your criteria for terminating the push. The machine to push the CPT into the ground can be a simple pusher machine or a more sophisticated crawler or truck. We produce a simple pusher but we are also reseller for Pagani CPT penetrometers. These are more complex and able but of course also quite a lot more costly.

Example of penetrometers are:

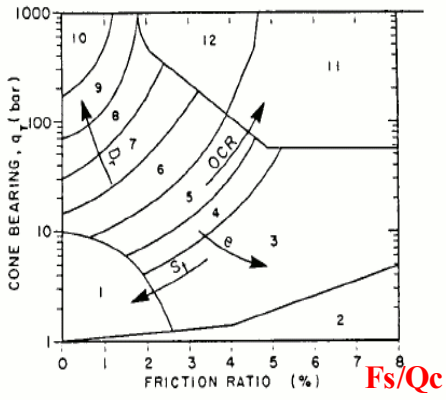
Pagani penetrometers are available in several and versions/sizes

The Envi pusher. Can be transported on a pickup and manually moved when on site using the combined transport- and power pack trolley

After retraction of the Memocone data is downloaded from the electronic memory and shown on screen. Data can be exported in a tab separated format suitable for import with Excel or equivalent or in Nordic standard format which is a tagged format. Data in files can be imported into analysis softwares where soil type etc can be determined. Our system also gives you the option to determine soil type etc in software. So you can see estimated soil type directly on screen in our application. To determine soil type the Robertson chart is often used:

Force on cone tip, Qc

$q_t = q_c + u_2(1-a)$



1. Sensitive fine-grained soil
2. Organic soil
3. Clay
4. Silty clay to clay
5. Clayey silt to silty clay
6. Sandy silt to clayey silt
7. Silty sand to sandy silt
8. Sand to silty sand
9. Sand
10. Sand to gravelly sand
11. Very stiff fine-grained soil
12. Overconsolidated or cemented sand to clayey sand

Why do CPT tests?

CPT tests can be done for several reasons. The most obvious being:

- Ground investigations to know the strata before planning for construction of buildings, roads, bridges, railways etc
- Determine ground water level and possibly also hydrological flux

The most obvious benefit of using the CPT rather than soil sampling is of course time and cost. You will be able to investigate a lot more using the CPT than a soil sampler. You can achieve very accurate perception of the grounds strata provided you are soft ground. The CPT can not be used in ground with much pebbeles or bolders and of course also not in rock. For these harder layers drill data recording or core sampling is required.

If you combine CPTu investigations with some soil samples you will have a very good perception of the ground conditions in the area you have investigated.

Some case stories

On our homepage www.envi.se you can see several case stories. We have tried to gather information about some different types of users and how they benefit from having our systems.

References

A very detailed description of CPT usage and also seismic test
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_368.pdf

The most important book on the subject is:
http://books.google.com.hk/books?id=ofbnE1xMl_kC&printsec=frontcover&hl=sv&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false